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SDC
SOLENOIDAL DETECTOR NOTES

MATCHING FORWARD TOROIDS TO A CENTRAL SOLENOID

T. H. Fields

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MATCHING FORWARD TOROIDS TO A CENTRAL SOLENOID

Thomas H. Fields
Argonne National Laboratory
Argonne, Illinois 60439

Abstract

Physics requirements and practical criteria for choosing superconducting toroid parameters for a solenoid detector system are described. Other approaches for momentum measurement of forward tracks are briefly outlined.

Introduction

The use of a superconducting toroid at forward angles to augment a central solenoid tracker was advocated by Jones[1] several years ago. At this conference, conceptual engineering designs of superconducting toroids for the SDC solenoid detector[2], as well as for the EMPACT all-toroid detector[3], have been described. The main purpose of this paper is to summarize the physics and other criteria for choosing the toroid parameters for a central solenoid detector. A second purpose is to briefly describe alternate approaches for achieving some of these physics capabilities at forward angles.

Momentum Accuracy

By using a toroid magnet in the forward angle region, momenta of forward-going muons can be measured more accurately than by using the solenoid central tracker alone. Such a toroid can substantially increase the momentum accuracy, detection efficiency, and Z° identification capability for rare multimuon events which are likely to be important in SSC experiments, such as Higgs$\to Z^\circ Z^\circ \to \mu^+\mu^-\mu^+\mu^-$. Fig. 1, which is adapted from the SDC Expression of Interest[2], shows the muon momentum accuracy as a function of angle (pseudo-rapidity) for both the solenoid and the toroid. Curves are shown for various values of P_T, and 100 GeV/c can be considered as a typical value for electroweak reactions. Note that the solenoid tracker and the toroid tracker both give fractional momentum measurement errors (solid lines) which are almost independent of angle at fixed P_T.
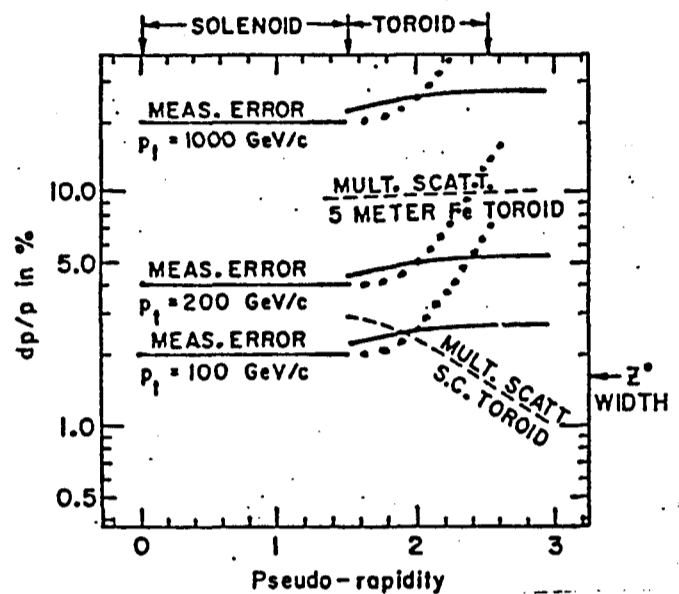

Fig. 1. Comparison of the muon momentum resolution of the SDC superconducting air-core toroid system with that of the central tracker. The solid lines show the resolutions $dp_T/p_T^2 = 0.2$ (TeV/c)$^{-1}$ for the central tracker and 0.25 (TeV/c)$^{-1}$ cosθ for the air-core toroids. The dashed lines show multiple-scattering contributions to the resolution of an air-core toroid and a toroid of magnetized iron. The dotted lines show the resolution which might be chosen for a small angle silicon strip tracking system in the solenoid region. Also shown is the resolution required to reconstruct the $Z(\to \mu\mu)$ mass with an error equal to the natural width of the Z.

Thus it is possible to match the toroid system to the solenoid system, giving a fractional momentum error (and thus a fractional dimuon mass error) which is nearly independent of angle over a wide region.

As Fig. 1 shows, the actual SDC parameters have been chosen to achieve a $Z^\circ \rightarrow \mu^+\mu^-$ mass resolution which is comparable to the Z° natural width, for muon P_T up to about 100 GeV/c. This is an important goal for dimuon mass precision, since identifying Z°'s reliably in the presence of significant backgrounds is likely to be necessary for the study of rare processes at the SSC. The main parameters which determine the toroid curves shown in Fig. 1 are the toroid field integral (8 Tm at r=2.3m), the drift chamber precision (10o microns/super-module, with 2-meter lever arms in front of and behind the toroid), and the muon entrance/exit wall thickness of the toroid (2-4 $X_\circ$). The latter determines the P_T-independent multiple scattering floor on the momentum accuracy of the superconducting toroid, shown as a dashed line in Fig. 1.

Toroid Design Goals

In addition to the momentum accuracy goals described above, there are important technical and practical criteria which need to be met by an engineering design for the super-conducting toroids. These criteria include reliability, safety, field uniformity, low leakage field, mobility, and minimum cost. Different engineering approaches to achieving these goals have been presented at this meeting and will require further evaluation before their technical tradeoffs and costs are accurately understood. Purcell has described a novel toroid design[4] which aims to achieve high reliability and low cost by using features, such as bath cooling of the superconductor, which have been proven technically conservative and highly cost effective in the performance of large superconducting magnets for bubble chambers.

Field uniformity and leakage field of the toroid are determined mainly by the number of discrete coils used. Fig.2

shows the leakage field for the SDC geometry as a function of the number of coils. In order to minimize problems with drift chamber operation and forces upon nearby iron structures, the number of coils should not be less than about 32. This arrangement will also yield good field uniformity.
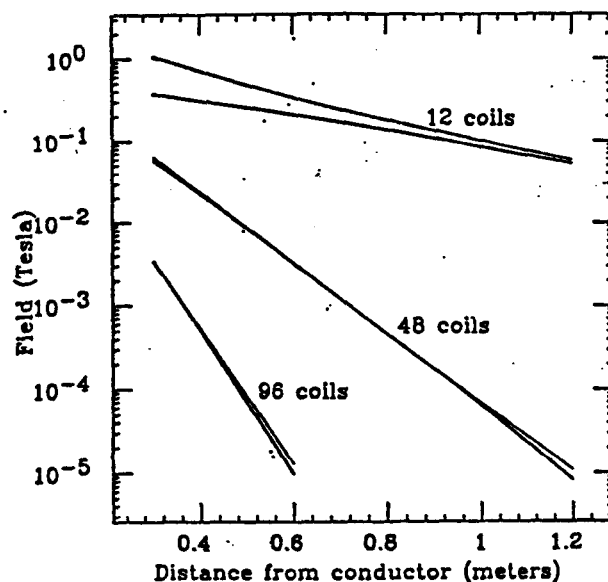

Fig. 2. The field outside the SDC toroid at maximum radius (6m), as a function of the number of (narrow) coils in the toroid. The distance is measured from the coil in the upstream axial (collider beam) direction. The field inside the toroid at this radius is about 1 Tesla. The two separate curves of each pair show the field within and between coil planes.

Other Methods For Measuring Forward Muons

For the SDC detector, several other methods can be used for making momentum measurements on forward angle muons. Choosing from among the available methods requires technical tradeoffs, accurate cost information, and relaxing the goal of closely matching the forward momentum accuracy to that of the central tracker. Brief descriptions of three possibilities are as follows:

1) Use a solid iron forward toroid rather than an air core superconducting toroid (ACT). This is expected to be less costly, and perhaps more reliable, than the ACT.

The iron toroid has disadvantages in momentum accuracy (dp/p is limited to about 10%, see Fig. 1), mobility (4000 tons instead of 80 tons), and in producing more electromagnetic showers along the muon track. Mobility is important for achieving access to service the central tracker and calorimeter systems.

2. Make precise track measurements at intermediate angles inside the solenoid using new types of silicon strip chambers and/or radial wire chambers. The dotted curves in Fig. 2 show the momentum precision which might be chosen for the SDC. Here the advantages include the accurate measurement of other charged tracks as well as muons. The potential disadvantages include pattern recognition problems and radiation damage at high luminosity, lack of a good muon trigger signal, and rapid loss of momentum accuracy at small angles.

3) Use a superconducting air core toroid of lower magnetic field strength which gives, say, dp/p=10%. Its physics performance would be comparable to that of an iron toroid, it might cost less than an iron toroid, and it would have advantages in mobility and reduced shower production, as described above.

Conclusions

Superconducting toroids which match the momentum accuracy of the central solenoid system can offer valuable physics capabilities, and appear to be quite feasible technically. Present cost estimates for superconducting toroids range from comparable to iron to much more, and are still uncertain. It is therefore important to continue to develop and evaluate designs which are aimed at low cost and high reliability. Alternate devices of somewhat lower cost involve performance compromises which might turn out to be serious for physics experiments on rare processes.

Present planning for the SDC Letter of Intent is to use both alternates 1) and 2) as described above, instead of superconducting toroids, in order to achieve a significant cost reduction from the SDC ACT cost estimate used in the EOI[2].

[1] L.W. Jones, Snowmass, 1986 Proceedings, p. 462.
[2] Solenoidal Detector Collaboration (SDC), Expression of Intent, May, 1990.
[3] EMPACT Detector Collaboration Expression of Intent, May 1990.
[4] J. Purcell, talk at this conference.